LNG Fuel Systems Technology

On-board LNG Pumps, Storage Tanks, and Heat Exchangers

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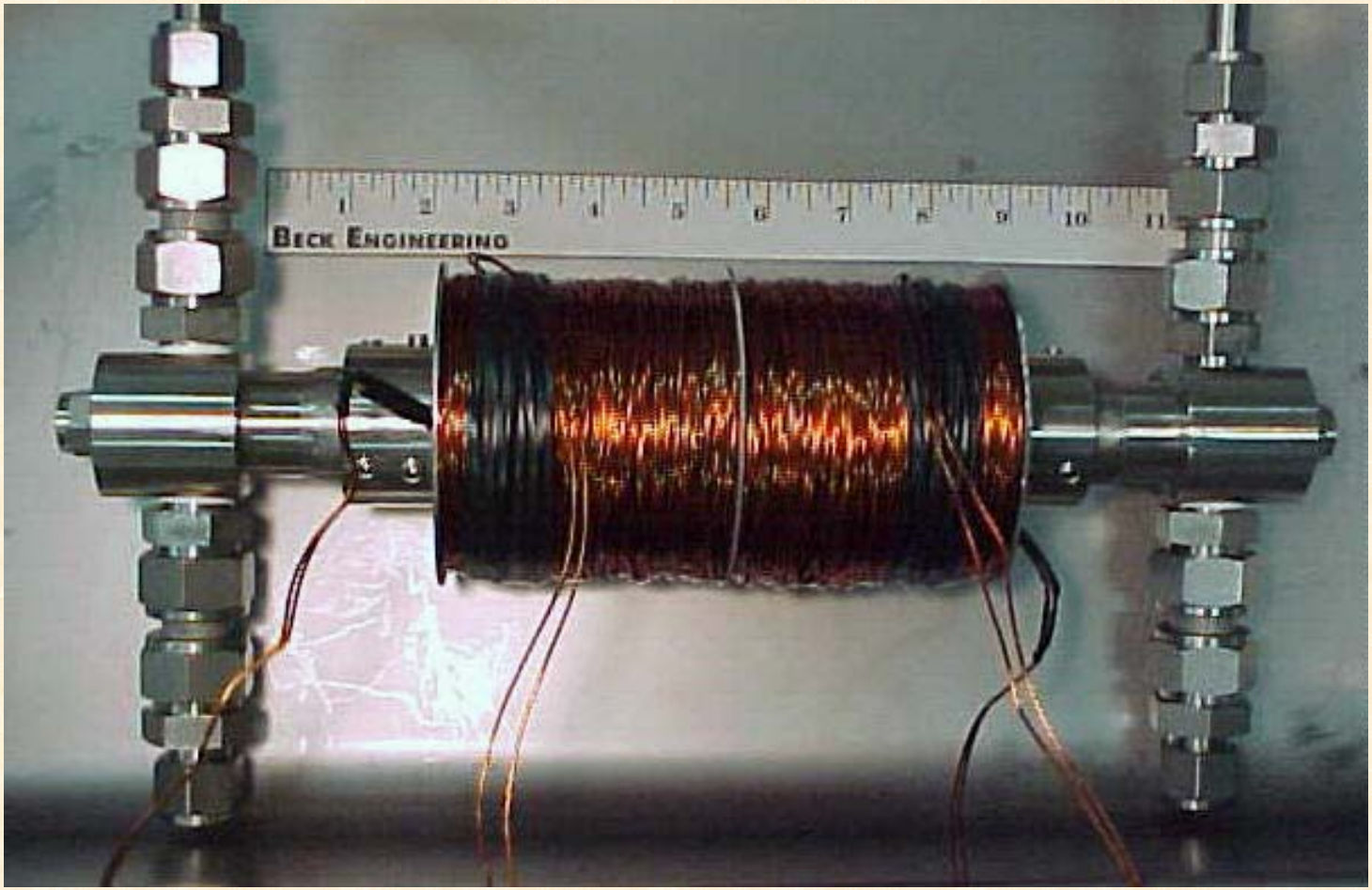
Method to the LNG Madness

- Well-to-Wheels System integration on selected markets
- 25% more on-board fuel storage
- Low-cost $90/dge LNG vehicle tanks
- 25% improvement in overall efficiency;
  small scale liquefiers, pumps for DING engines,
  use of cold LNG energy, no atmospheric venting

Beck Free-Piston Cryogenic Pump

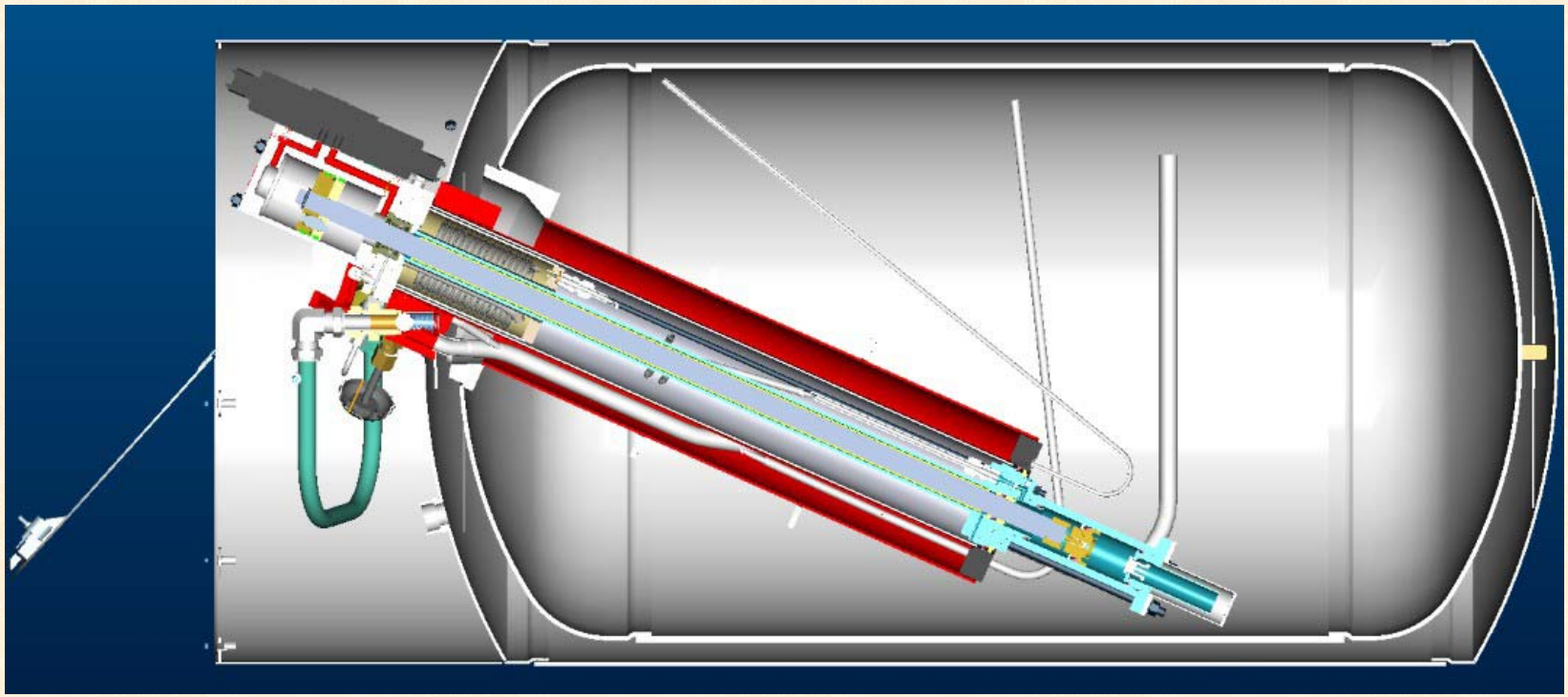


Beck Project Goals and Accomplishments

- Compact, reliable, electric-driven, on-board LNG pump for 3600 psi service
- Liquid flow of 45 ml/s (achieved 17ml/s)
- Non-contact, dynamic seals (not achieved)
- Low cost at $500 to $1,000 per unit
- Newer version has higher flow rates, simpler design with reduced internal heating

Cummins/Westport/Taylor-Wharton

LNG Tank/Pump



Design Approach

Feature or Component	Design Approach	Rationale and Remarks
LNG Storage Strategy	Low-pressure dense saturated liquid pumped to pressure required by engine.	No fuel conditioning required. Maximum vehicle range and hold time (for given MAWP). Simplifies fueling station.
LNG Tank Design	Cryogenic dewar with VJ, MLI, and strong low-conductivity suspension. Designed to ASME; meets the requirements of NFPA 57, SAE J2343, CCR Title 13, and Texas Administration Code Title 16.	Proven cryogenic technology with CWI and Taylor-Wharton design features for minimum heat leak and low-cost manufacturability. Designed to pass drop test per SAE J2343.

Feature or Component	Design Approach	Rationale and Remarks
Pump	Zero-NPSH two-stage reciprocating uni-flow pump. High-pressure and lighter-weight low-pressure versions.	Configuration is a high-durability and low-cost design evolved from over 5000 hours of laboratory testing and 3000 hours of road testing.
Pump Placement	Pump installed in fuel tank through low-heat-leak nozzle and VJ sleeve.	Internal pump requires no cool down, minimizes vapor generation, and provides compact package. Easily removed for servicing. Flow path of LNG reduces heat leak to tank during pump operation.
Pump Drive	Compact hydraulic drive unit within tank shroud. Integral electric hydraulic pump for low pressure.	Engine-driven hydraulic pump for high pressure. Reliable and durable hydraulic drive has low parts count (e.g., no limit switches).

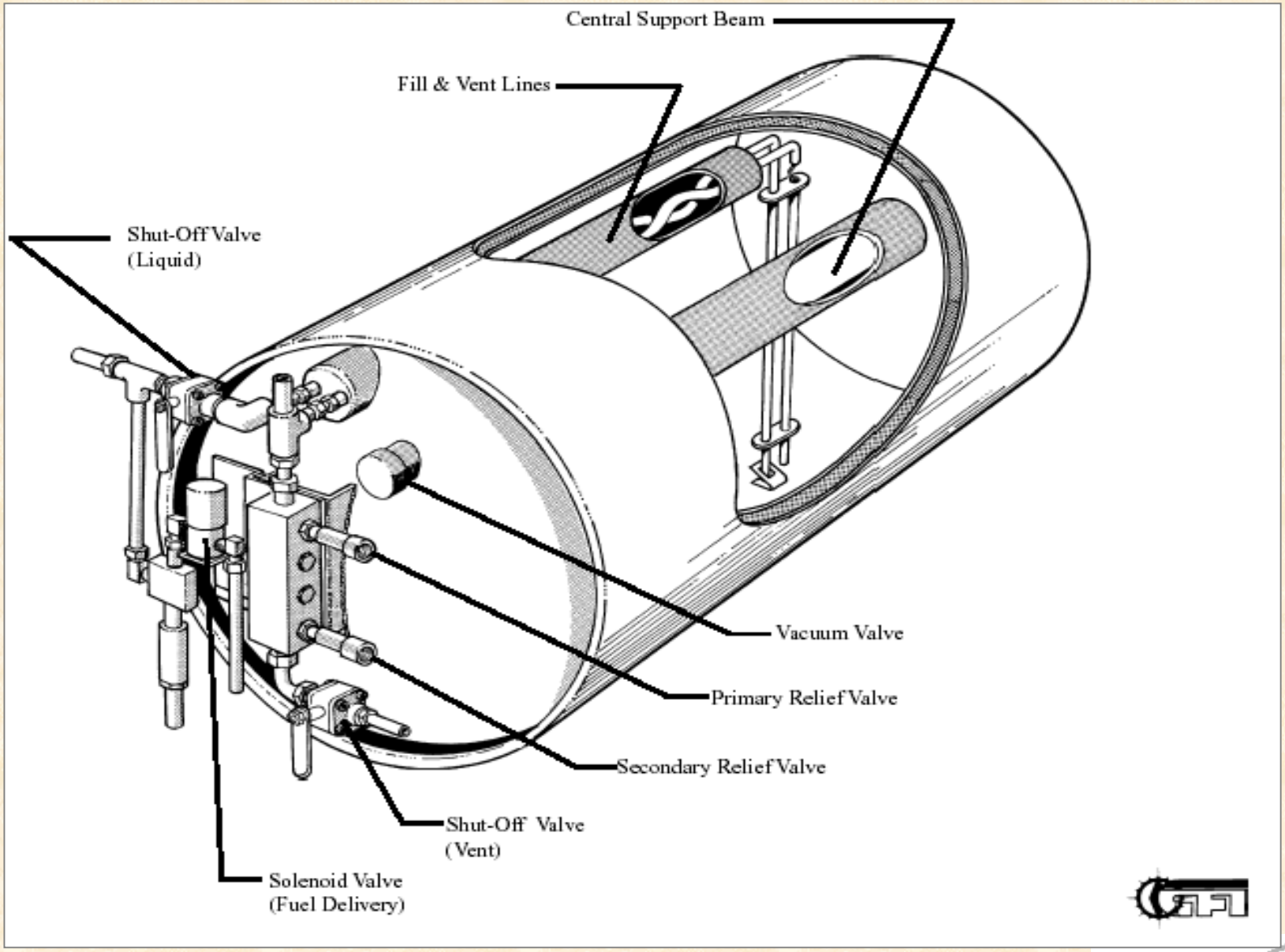
Feature or Component	Design Approach	Rationale and Remarks
Vaporizer	Single-pass coiled tubes in annular shell concentric around pump shaft.	Provides very compact integrated fuel system. Vaporizer performance proven through testing.
Refueling	Either one-line (ullage vapor collapse) or two-line refueling can be incorporated.	Current system is one-line fill with either Parker or Carter couplings. Advantages of two-line fill will be explored.
Fuel-Level Sensor	Capacitance style gauge with 0.5V to 4.5V output.	Removable design inserted through outer flange of tank. Signal conditioner compatible with commercial fuel gauges.
Balance of System	Pump performance including over-pressure capability does not require accumulator.	Simplifies installation. Prior pumped LNG systems required a small CNG tank.

Cummins/Westport Task Schedule

ALOSS Project Tasks	Resource Requirements	
	Categories	Man-hours
Task 1 - ALOSS Design - Design ALOSS components, and review designs for manufacturability	DE, ME, C	1992
Task 2 - Component Fabrication - Manufacture ALOSS hardware, and perform quality control inspections	ME	80 *
* *Manufacturing labor is included in the unit cost; the labor shown above is for quality control inspections only.*		
Task 3 - Test Stand Setup - Modify existing LNG tank and pump test rigs, and commission rigs with ALOSS components.	TE, TT	200
Task 4 - Component and System Testing - Conduct NER tests, component and system functional tests, and laboratory durability tests.	TE, TT	4440
Task 5 - Performance Analysis - Evaluate functional and durability test data, and identify areas for ALOSS improvement.	DE, TE, ME, C, PM	760
Project Management and Reporting - Conduct regular meetings, prepare quarterly progress reports and project final report.	PM, C, DE, TE, ME	1110
Legend: PM: Project Manager TT: Test Technician TE: Test Engineer DE: Design Engineer ME: Manufacturing Engineer C: Consultant		

CFI/TPI Project Goals

- Supplier competition in the LNG tank market
- Sale price of $90/dge when manufacturing 1,000 tanks per year
- Complete fill with +/- 10% fuel gauge accuracy
- Offer a vacuum warranty of five years (not in original DOE contract)
- Meets all codes and regulations (except fire test)
- Contract completion date: June 1, 2003


Central Support Beam
Fill & Vent Lines
Shut-Off Valve
(Liquid)
Vacuum Valve
Primary Relief Valve
Secondary Relief Valve
Shut-Off Valve
(Vent)
Solenoid Valve
(Fuel Delivery)

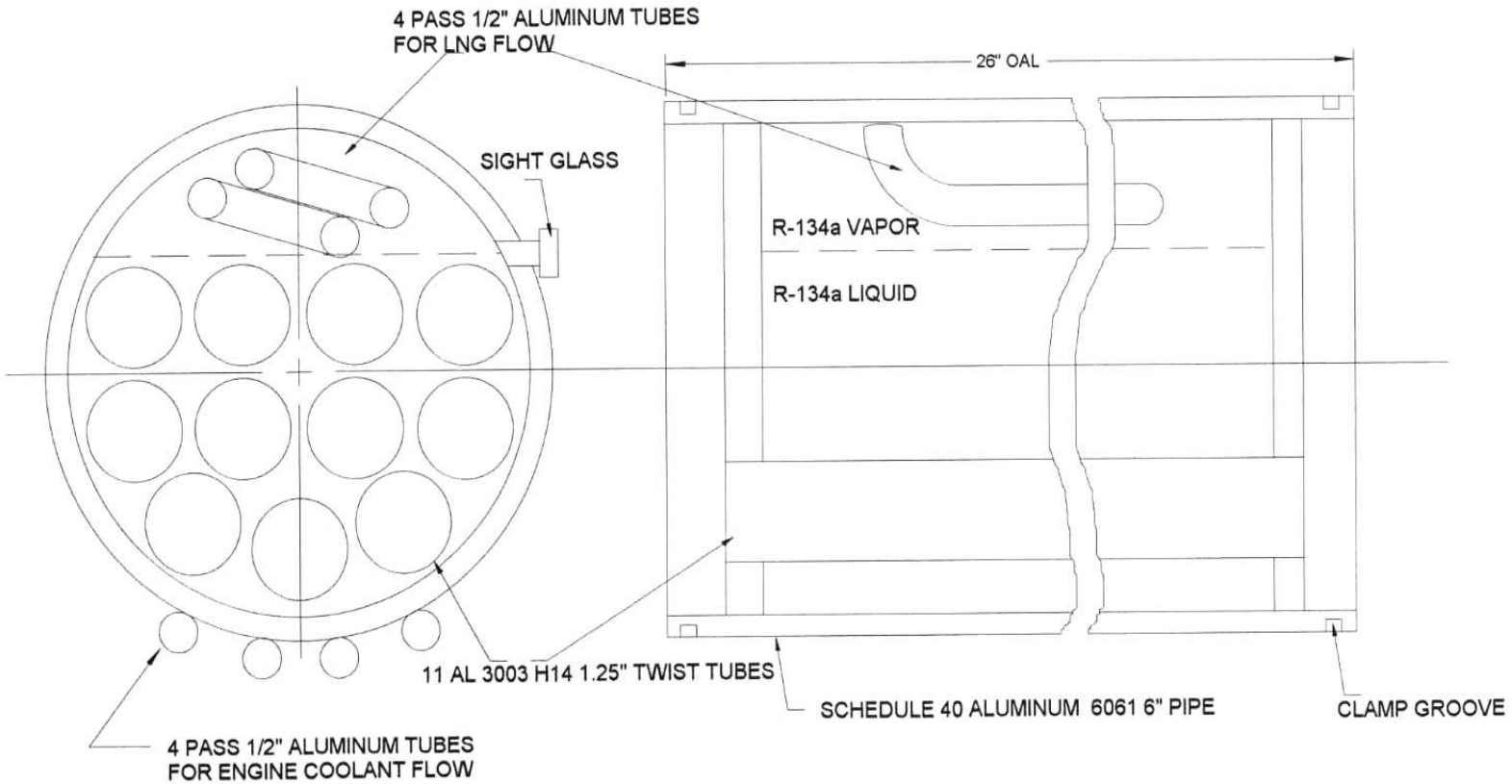
DROP TEST 30' SAE-J-2343 CERTIFICATION

ATM Intercooler for Recovery of LNG "Cold Energy"

- DOE contracted with Advanced Technologies Management (ATM) for proof-of-concept
- Initial LNG Test at ATMI showed some NOx reduction and nearly 10% increase in the engine's power density
- Water droplet formation is the only problem
- ATM is addressing the water management issue

PROTOTYPE UNITARY HEAT EXCHANGER ASSEMBLY

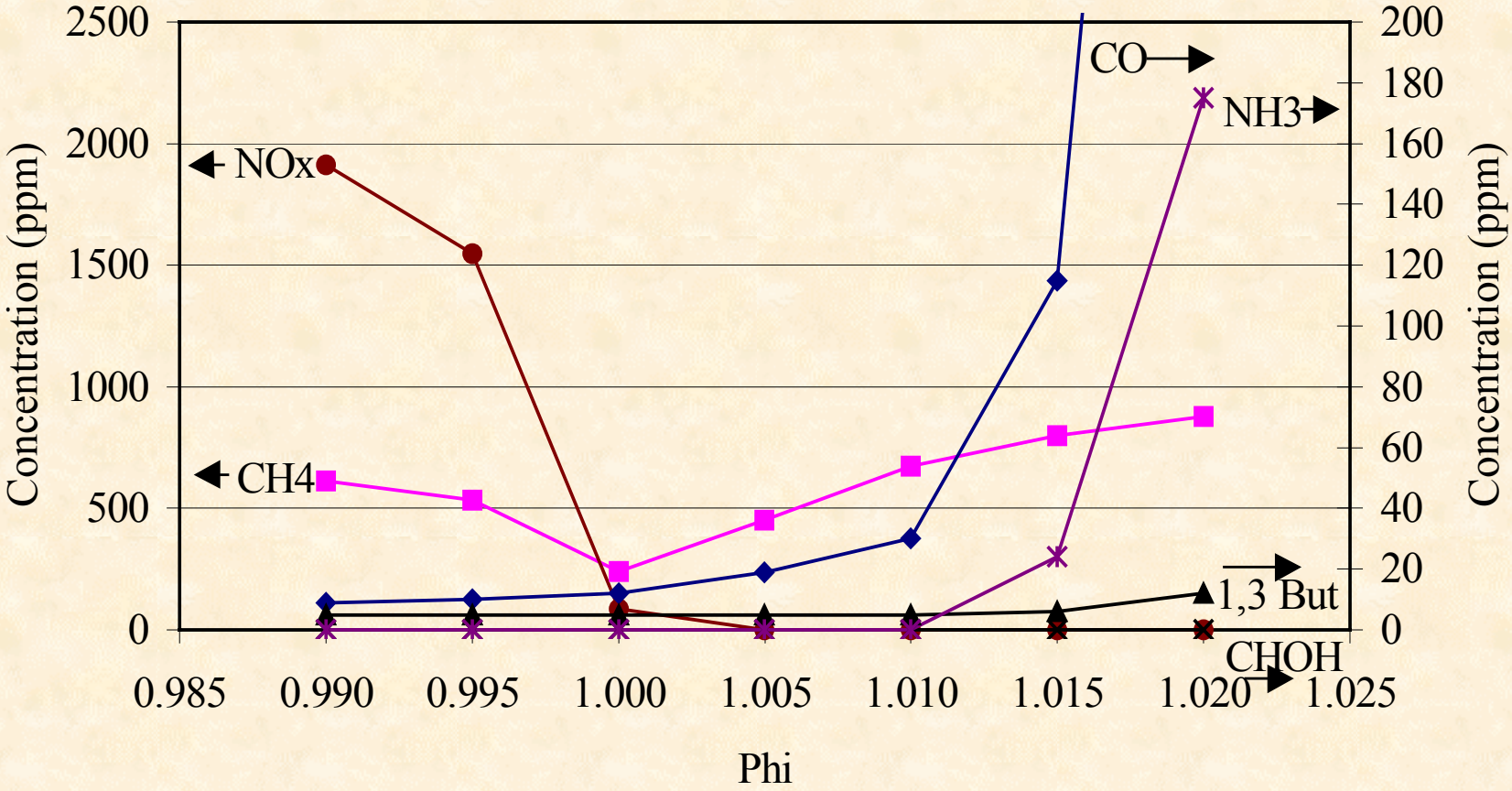
ONE HALF SCALE
INSULATION & TRANSITIONS TO 4 INCH AIR PIPES NOT SHOWN
INSTRUMENTATION & PRESSURE RELIEF ATTACHMENTS NOT SHOWN



ATM Goals and Accomplishments

- **Goal:** The ability to get the same power output from a down-sized engine and go stoichiometric without penalty
- **Accomplishments:**
  - 17.8% reduction in NOx
  - nearly 40% reduction in HC
  - 30.7% increase in knock-limit power output
- **Complete Test Results:** SAE-2001-01-3682 (James Chui)
- **Current Status:** ATM is actively marketing the concept
- **Future Work:** Apply “cold energy” to tail pipe EGR

SwRI High EGR & TWC Emissions



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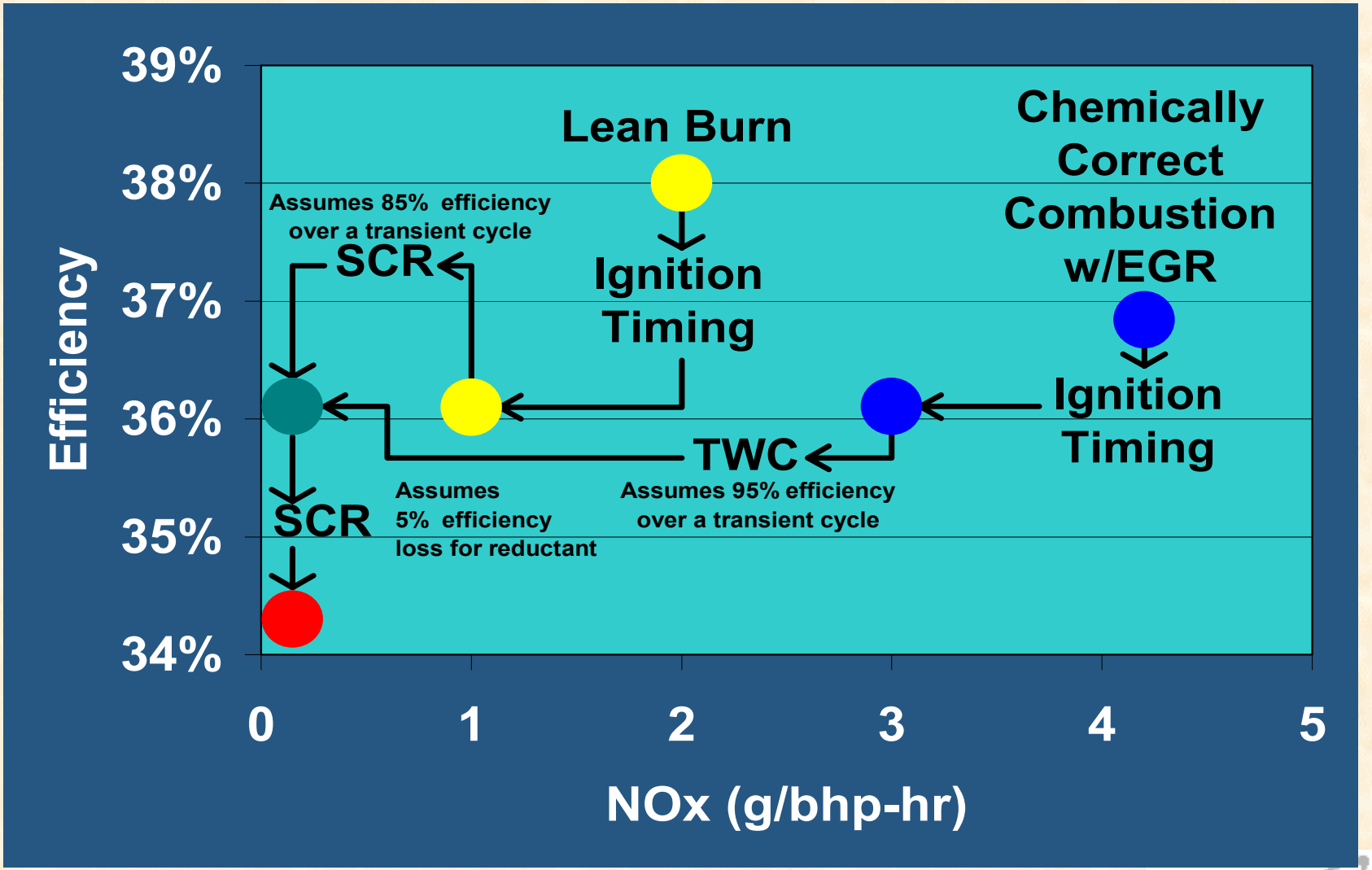
SwRI Approach to 2007 EPA Standards



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Proposed NGV Program Goal